



US009471278B2

(12) **United States Patent**
Nandi et al.

(10) **Patent No.:** **US 9,471,278 B2**
(45) **Date of Patent:** **Oct. 18, 2016**

(54) **LOW AREA FULL ADDER WITH SHARED TRANSISTORS**

(56) **References Cited**

U.S. PATENT DOCUMENTS

(71) Applicant: **Texas Instruments Incorporated**,
Dallas, TX (US)

(72) Inventors: **Suvam Nandi**, Bangalore (IN);
Badarish Mohan Subbannavar,
Bangalore (IN)

(73) Assignee: **TEXAS INSTRUMENTS**
INCORPORATED, Dallas, TX (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 210 days.

3,843,876 A * 10/1974 Fette G06F 7/503
708/702

4,713,790 A * 12/1987 Kloker G06F 7/503
326/53

4,733,365 A * 3/1988 Nagamatsu H03K 19/215
708/702

4,831,578 A * 5/1989 Bui G06F 7/501
708/702

5,233,233 A * 8/1993 Inoue G06F 7/503
326/21

5,617,345 A * 4/1997 Kamijo G06F 7/5318
708/620

2016/0092170 A1 * 3/2016 Nandi G06F 7/50
708/230

* cited by examiner

Primary Examiner — David H Malzahn

(74) *Attorney, Agent, or Firm* — John R. Pessetto; Frank
D. Cimino

(21) Appl. No.: **14/496,767**

(22) Filed: **Sep. 25, 2014**

(65) **Prior Publication Data**

US 2016/0092170 A1 Mar. 31, 2016

(51) **Int. Cl.**
G06F 7/501 (2006.01)
G06F 7/50 (2006.01)
H03K 19/20 (2006.01)
H03K 19/00 (2006.01)

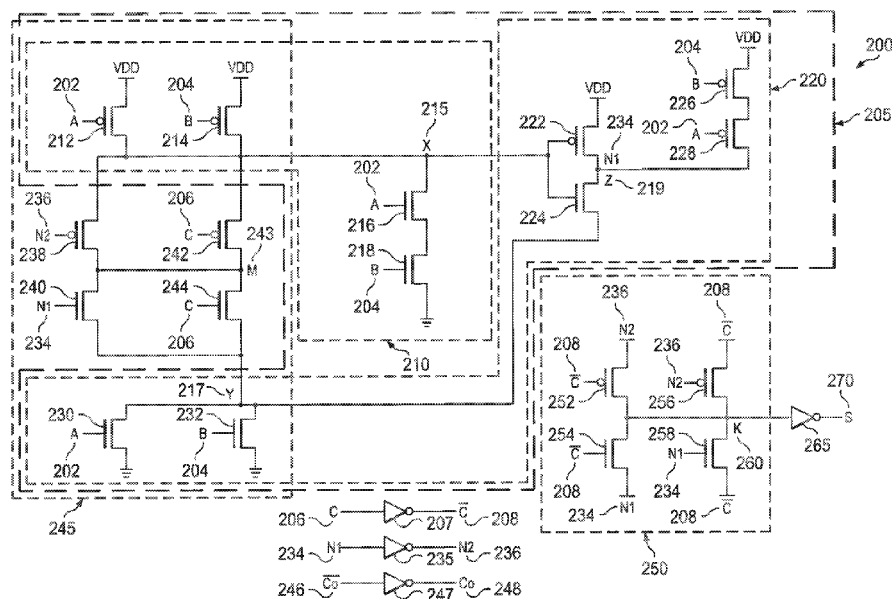
(52) **U.S. Cl.**
CPC **G06F 7/50** (2013.01); **H03K 19/0013**
(2013.01); **H03K 19/20** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(57) **ABSTRACT**

A full adder is disclosed that utilizes low area. The full adder includes an exclusive NOR logic circuit. The exclusive NOR logic circuit receives a first input and a second input. A first inverter receives an output of the exclusive NOR logic circuit and generates an exclusive OR output. A carry generation circuit receives the output of the exclusive NOR logic circuit, the exclusive OR output and a third input. The carry generation circuit generates an inverted carry. A second inverter is coupled to the carry generation circuit and generates a carry on receiving the inverted carry. A sum generation circuit receives the output of the exclusive NOR logic circuit, the exclusive OR output and the third input. The sum generation circuit generates an inverted sum. A third inverter is coupled to the sum generation circuit and generates a sum on receiving the inverted sum.

18 Claims, 3 Drawing Sheets



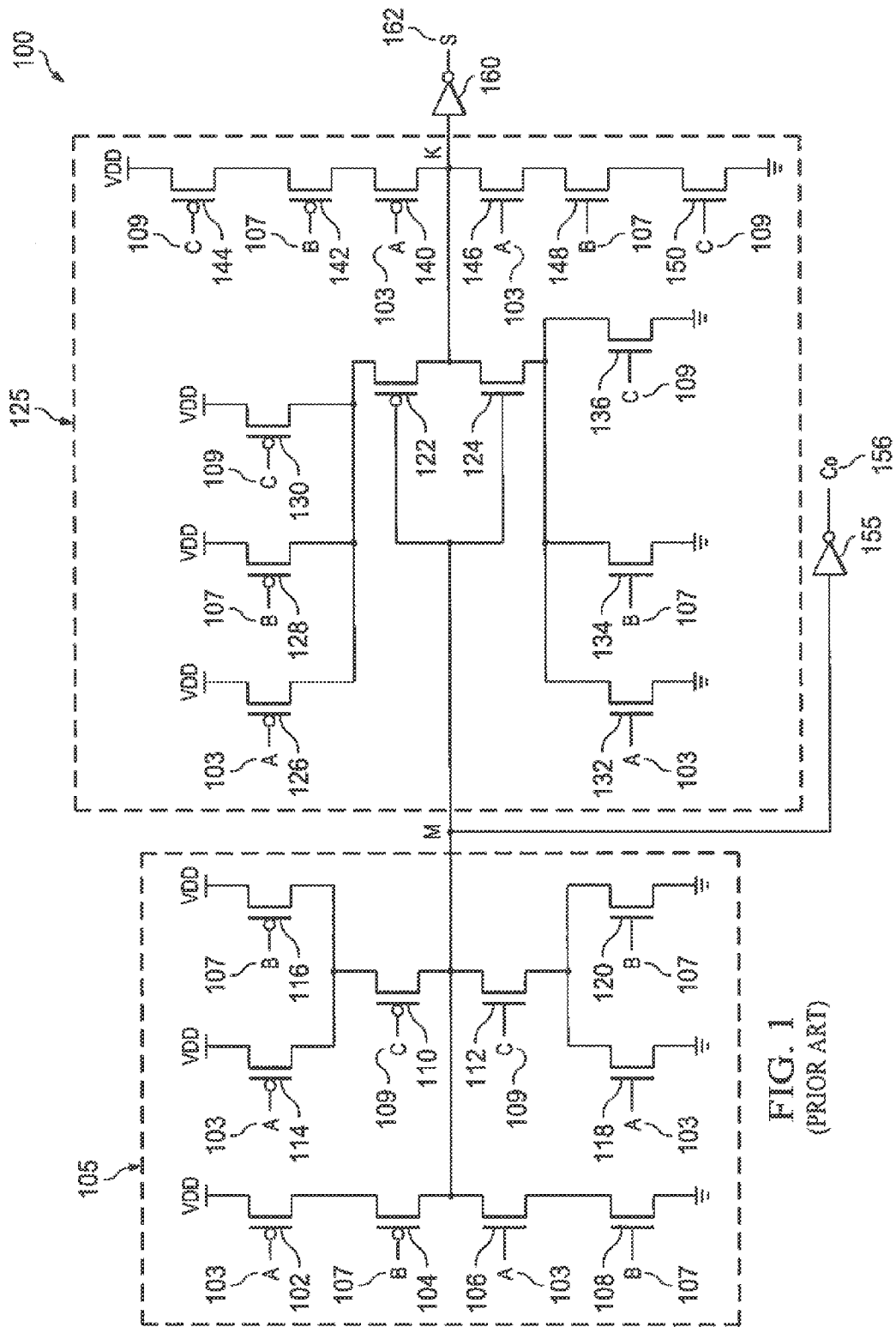


FIG. 1
(PRIOR ART)

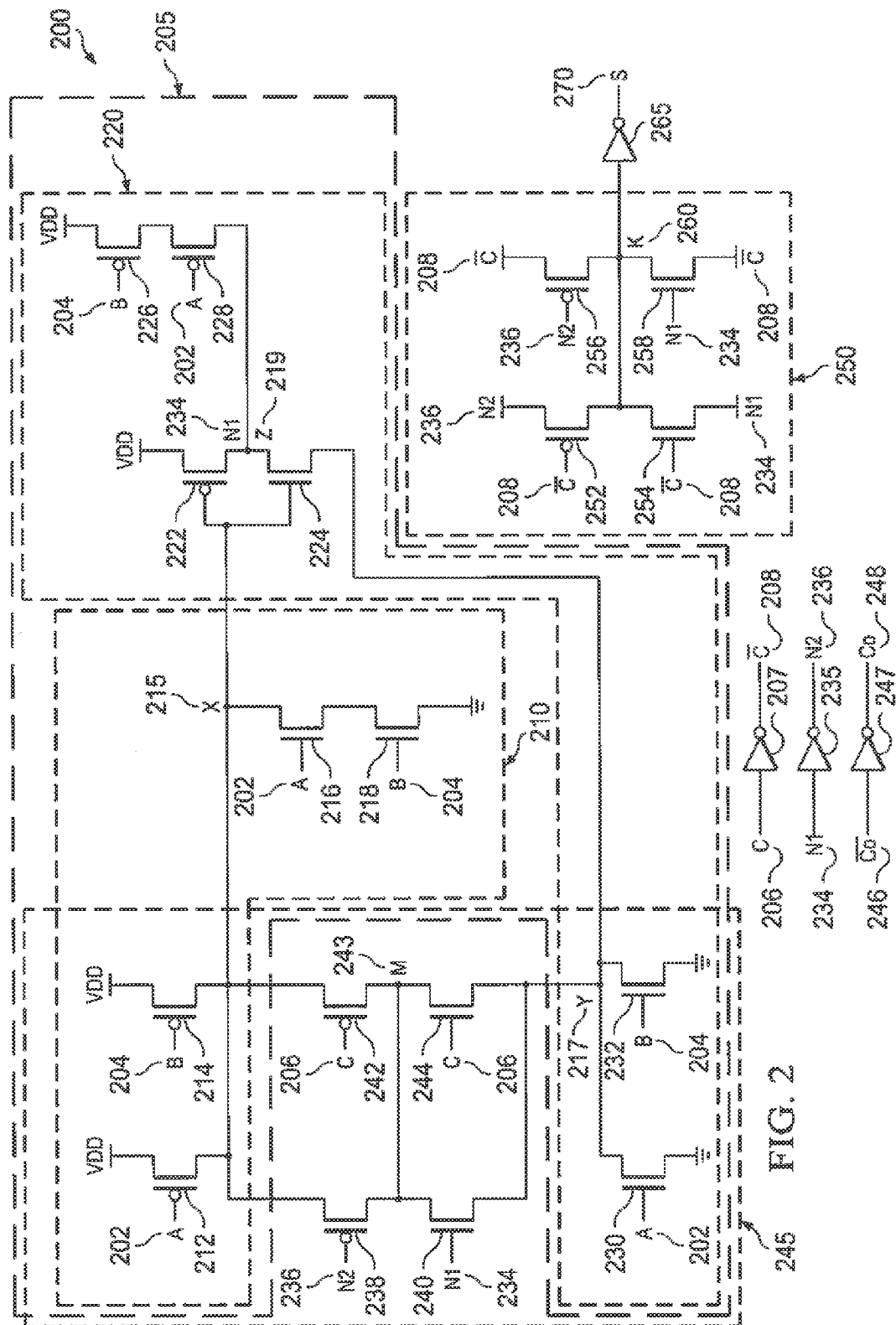


FIG. 2

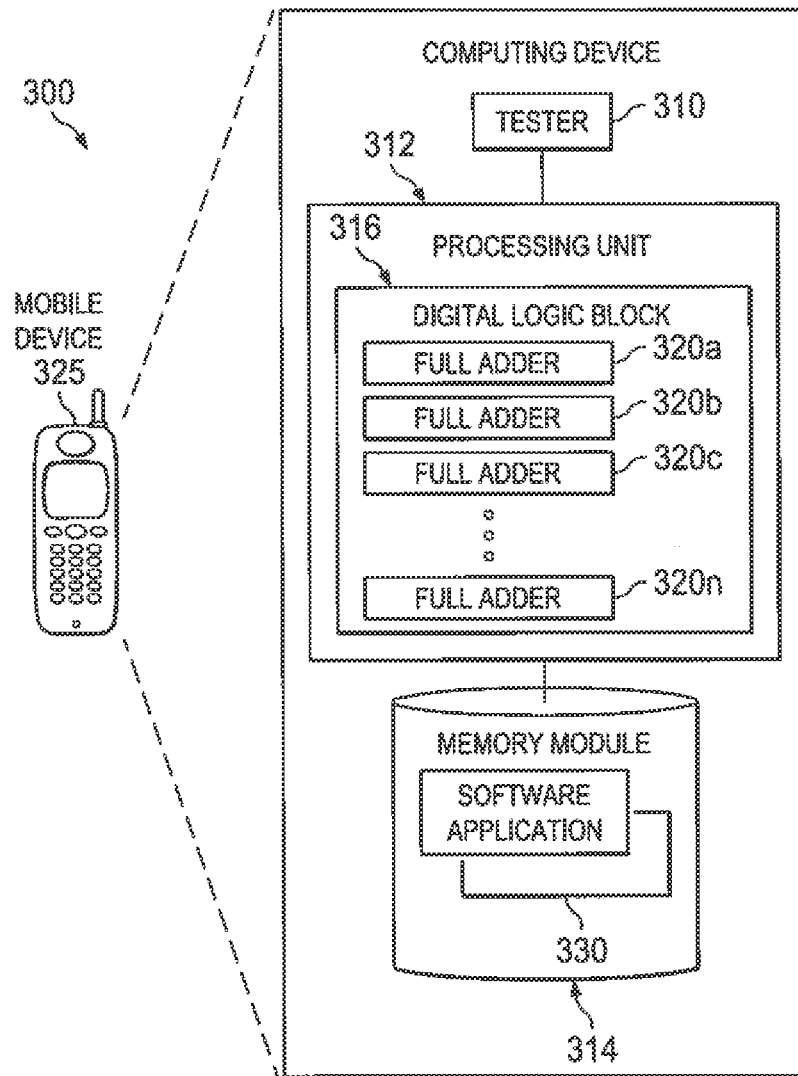


FIG. 3

1

LOW AREA FULL ADDER WITH SHARED TRANSISTORS

TECHNICAL FIELD

The present invention relates to an integrated circuit, and more particularly, to a full adder implemented using MOS transistors.

BACKGROUND

As a result of the continuous developments in integrated circuits (ICs), the full adders contribute to a substantial portion of any circuit design's area and power. The various units of an IC that consume power are logic implementation, full adders, flip flops, RAM, clock tree and integrated clock gating (ICG) cells. The full adders consume 30-40% of the total area and 30-40% of the total power in a typical digital design.

The power consumed by a full adder is directly proportional to a number of transistors used for implementing the full adder. Thus, it is apparent that with reduced transistor count, the power consumed by the full adder can also be reduced. Also, a reduction in area of the full adder will directly translate to reduction in chip area and saving of costs. Also, since the full adders are most critical in the data path, improving the area and power consumed by the full adder improves the performance of the digital designs using the full adder.

SUMMARY

This Summary is provided to comply with 37 C.F.R. §1.73, requiring a summary of the invention briefly indicating the nature and substance of the invention. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

An embodiment provides a full adder. The full adder includes an exclusive NOR logic circuit. The exclusive NOR logic circuit receives a first input and a second input. A first inverter receives an output of the exclusive NOR logic circuit and generates an exclusive OR output. A carry generation circuit receives the output of the exclusive NOR logic circuit, the exclusive OR output and a third input. The carry generation circuit generates an inverted carry. A second inverter is coupled to the carry generation circuit and generates a carry on receiving the inverted carry.

A sum generation circuit receives the output of the exclusive NOR logic circuit, the exclusive OR output and the third input. The sum generation circuit generates an inverted sum. A third inverter is coupled to the sum generation circuit and generates a sum on receiving the inverted sum.

Other aspects and example embodiments are provided in the Drawings and the Detailed Description that follows.

BRIEF DESCRIPTION OF THE VIEWS OF DRAWINGS

FIG. 1 illustrates a conventional full adder;

FIG. 2 illustrates a full adder, according to an embodiment; and

FIG. 3 illustrates a computing device, according to an embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. 1 illustrates a conventional full adder 100. The conventional full adder 100 includes a carry generation

2

circuit 105, a sum generation circuit 125, a first inverter 155 and a second inverter 160. The carry generation circuit 105 is explained now. The carry generation circuit 105 includes a first PMOS transistor 102 whose gate terminal receives a first input A 103 and whose source terminal is coupled to a power terminal VDD. A drain terminal of the first PMOS transistor 102 is coupled to a source terminal of a second PMOS transistor 104. A gate terminal of the second PMOS transistor 104 receives a second input B 107.

A drain terminal of the second PMOS transistor 104 is coupled to a first node M. The carry generation circuit 105 further includes a first NMOS transistor 106 whose gate terminal receives a first input A 103 and whose drain terminal is coupled to the first node M. A source terminal of the first NMOS transistor 106 is coupled to a drain terminal of a second NMOS transistor 108. A gate terminal of the second NMOS transistor 108 receives the second input B 107 and a source terminal of the second NMOS transistor 108 is coupled to a ground terminal.

The carry generation circuit 105 further includes a third PMOS transistor 114, a fourth PMOS transistor 116, a fifth PMOS transistor 110, a third NMOS transistor 118, a fourth NMOS transistor 120 and a fifth NMOS transistor 112. A gate terminal of the third PMOS transistor 114 receives the first input A 103 and a source terminal of the third PMOS transistor 114 is coupled to the power terminal VDD. A gate terminal of the fourth PMOS transistor 116 receives the second input B 107 and a source terminal of the fourth PMOS transistor 116 is coupled to the power terminal VDD.

A drain terminal of the third PMOS transistor 114 and a drain terminal of the fourth PMOS transistor 116 are coupled to a source terminal of the fifth PMOS transistor 110. A gate terminal of the fifth PMOS transistor 110 receives a third input C 109 and a drain terminal of the fifth PMOS transistor 110 is coupled to the first node M.

A gate terminal of the third NMOS transistor 118 receives the first input A 103 and a source terminal of the third NMOS transistor 118 is coupled to the ground terminal. A gate terminal of the fourth NMOS transistor 120 receives the second input B 107 and a source terminal of the fourth NMOS transistor 120 is coupled to the ground terminal.

A drain terminal of the third NMOS transistor 118 and a drain terminal of the fourth NMOS transistor 120 are coupled to a source terminal of the fifth NMOS transistor 112. A gate terminal of the fifth NMOS transistor 112 receives a third input C 109 and a drain terminal of the fifth NMOS transistor 112 is coupled to the first node M and to the drain terminal of the fifth PMOS transistor 110.

The first node M receives an output of the carry generation circuit 105. The first inverter 155 is coupled to the first node M and generates a carry Co 156 on receiving the output of the carry generation circuit 105. The sum generation circuit 125 is explained now. The sum generation circuit 125 is coupled to the first node M and receives the output of the carry generation circuit 105. A gate terminal of each of a sixth PMOS transistor 126, a seventh PMOS transistor 128 and an eighth PMOS transistor 130 receive the first input A 103, the second input B 107 and the third input C 109 respectively.

A source terminal of each of the sixth PMOS transistor 126, the seventh PMOS transistor 128 and the eighth PMOS transistor 130 is coupled to the power terminal VDD. A drain terminal of each of the sixth PMOS transistor 126, the seventh PMOS transistor 128 and the eighth PMOS transistor 130 is coupled to a source terminal of a ninth PMOS transistor 122.

3

A gate terminal of each of a sixth NMOS transistor **132**, a seventh NMOS transistor **134** and an eighth NMOS transistor **136** receive the first input A **103**, the second input B **107** and the third input C **109** respectively. A source terminal of each of the sixth NMOS transistor **132**, the seventh NMOS transistor **134** and the eighth NMOS transistor **136** is coupled to the ground terminal. A drain terminal of each of the sixth NMOS transistor **132**, the seventh NMOS transistor **134** and the eighth NMOS transistor **136** is coupled to a source terminal of a ninth NMOS transistor **124**.

A gate terminal of each of the ninth PMOS transistor **122** and the ninth NMOS transistor **124** are coupled to the first node M and receive the output of the carry generation circuit **105**. A drain terminal of the ninth PMOS transistor **122** and a drain terminal of the ninth NMOS transistor **124** are coupled to a second node K.

A gate terminal of each of a tenth PMOS transistor **140**, an eleventh PMOS transistor **142** and a twelfth PMOS transistor **144** receive the first input A **103**, the second input B **107** and the third input C **109** respectively. A source terminal of the twelfth PMOS transistor **144** is coupled to the power terminal VDD. A drain terminal of the twelfth PMOS transistor **144** is coupled to a source terminal of the eleventh PMOS transistor **142** and a drain terminal of the eleventh PMOS transistor **142** is coupled to a source terminal of the tenth PMOS transistor **140**.

A gate terminal of each of a tenth NMOS transistor **146**, an eleventh NMOS transistor **148** and a twelfth NMOS transistor **150** receive the first input A **103**, the second input B **107** and the third input C **109** respectively. A source terminal of the twelfth NMOS transistor **150** is coupled to the ground terminal. A drain terminal of the twelfth NMOS transistor **150** is coupled to a source terminal of the eleventh NMOS transistor **148** and a drain terminal of the eleventh NMOS transistor **148** is coupled to a source terminal of the tenth NMOS transistor **146**.

A drain terminal of the tenth PMOS transistor **140** and a drain terminal of the tenth NMOS transistor **146** are coupled to the second node K. The second node K receives an output of the sum generation circuit **125**. The second inverter **160** is coupled to the second node K and generates a sum S **162** on receiving the output of the sum generation circuit **125**.

The operation of the conventional full adder **100** illustrated in FIG. 1 is explained now. The carry generation circuit **105** receives the first input A **103**, the second input B **107** and the third input C **109** and generates an inverted carry at the first node M. The inverted carry is defined as:

$$\text{Inverted Carry } (\overline{Co}) = \overline{AB+BC+CA} \quad (1)$$

The first inverter **155** receives the inverted carry generated at node M. The first inverter **155** generates a carry Co **156** on receiving the inverted carry (\overline{Co}). The sum generation circuit **125** receives the inverted carry from the carry generation circuit **105**, and the first input A **103**, the second input B **107** and the third input C **109**. The sum generation circuit **125** generates an inverted sum at the second node K. The inverted sum is defined as:

$$\text{Inverted Sum} = \overline{(A+B+C)(\overline{Co})+ABC} \quad (2)$$

The second inverter **160** is coupled to the second node K and generates a sum S **162** on receiving the inverted sum. The conventional full adder **100** utilizes a minimum of 28 transistors. Also, there is a dependency of the sum S **162** on the inverted carry which reduces the processing speed.

FIG. 2 illustrates a full adder **200**, according to an embodiment. The full adder **200** includes an exclusive NOR

4

logic circuit **205**, a carry generation circuit **245**, a sum generation circuit **250**, a first inverter **235**, a second inverter **247**, a third inverter **265** and a fourth inverter **207**. The exclusive NOR logic circuit **205** receives the first input A **202** and a second input B **204**. The first inverter **235** receives an output N1 **234** of the exclusive NOR logic circuit **205** and generates the exclusive OR output N2 **236**.

The exclusive NOR logic circuit **205** includes a first NAND logic circuit **210** and a second NAND logic circuit **220**. The first NAND logic circuit **210** receives the first input A **202** and the second input B **204**. The second NAND logic circuit **220** receives an output of the first NAND logic circuit **210**, the first input A **202** and the second input B **204**. The second NAND logic circuit **220** generates the output N1 **234** of the exclusive NOR logic circuit **205**.

The first NAND logic circuit **210** includes a first PMOS transistor **212** whose gate terminal receives the first input A **202** and whose drain terminal is coupled to a first node X **215**. A gate terminal of a second PMOS transistor **214** receives the second input B **204** and a drain terminal of the second PMOS transistor **214** is coupled to the first node X **215**. A source terminal of each of the first PMOS transistor **212** and the second PMOS transistor **214** is coupled to a power terminal VDD.

The first NAND logic circuit **210** also includes a first NMOS transistor **216** and a second NMOS transistor **218**. A gate terminal of the first NMOS transistor **216** receives the first input A **202** and a drain terminal of the first NMOS transistor **216** is coupled to the first node X **215**. A gate terminal of the second NMOS transistor **218** receives the second input B **204** and a drain terminal of the second NMOS transistor **218** is coupled to a source terminal of the first NMOS transistor **216**. A source terminal of the second NMOS transistor **218** is coupled to a ground terminal.

The second NAND logic circuit **220** is coupled to the first NAND logic circuit **210**. The second NAND logic circuit **220** is explained now. A gate terminal of a third PMOS transistor **222** is coupled to the first node X **215**. A source terminal of the third PMOS transistor **222** is coupled to the power terminal VDD. A gate terminal of the third NMOS transistor **224** is coupled to the first node X **215**. A source terminal of the third NMOS transistor **224** is coupled to a second node Y **217**. A drain terminal of the third NMOS transistor **224** is coupled to a drain terminal of the third PMOS transistor **222** to form a third node Z **219**.

A gate terminal of the fourth PMOS transistor **226** receives the second input B **204**. A source terminal of the fourth PMOS transistor **226** is coupled to the power terminal VDD. A gate terminal of a fifth PMOS transistor **228** receives the first input A **202**. A drain terminal of the fifth PMOS transistor **228** is coupled to the third node Z **219**. A source terminal of the fifth PMOS transistor **228** is coupled to a drain terminal of the fourth PMOS transistor **226**.

A gate terminal of a fourth NMOS transistor **230** receives the first input A **202**. A source terminal of the fourth NMOS transistor **230** is coupled to the ground terminal. A gate terminal of a fifth NMOS transistor **232** receives the second input B **204**. A source terminal of the fifth NMOS transistor **232** is coupled to the ground terminal. A drain terminal of the fifth NMOS transistor **232** is coupled to a drain terminal of the fourth NMOS transistor **230** to form the second node Y **217**.

The output N1 **234** of the exclusive NOR logic circuit **205** is generated at the third node Z **219**. The output N1 **234** is defined as:

$$N1 = A \text{ XNOR } B = \overline{(A \oplus B)} = \overline{AB + (\overline{A+B})} \quad (3)$$

5

Thus, the exclusive NOR logic circuit **205** performs XNOR logic operation (exclusive NOR logic operation) on the first input A **202** and the second input B **204**. The first inverter **235** is coupled to the third node Z **219** and receives the output N1 **234** of the exclusive NOR logic circuit **205**. The first inverter **235** generates the exclusive OR output N2 **236** by inverting the output N1 **234** of the exclusive NOR logic circuit **205**. The exclusive OR output N2 is defined as:

$$N2 = A \text{ XOR } B = \overline{A}B + A\overline{B} \quad (4)$$

Thus, a XOR logic operation is performed on the first input A **202** and the second input B **204** to obtain the exclusive OR output N2. The carry generation circuit **245** includes a sixth PMOS transistor **238**, a sixth NMOS transistor **240**, a seventh PMOS transistor **242** and a seventh NMOS transistor **244**. The first PMOS transistor **212**, the second PMOS transistor **214**, the fourth NMOS transistor **230** and the fifth NMOS transistor **232** are shared between the carry generation circuit **245** and the exclusive NOR logic circuit **205**.

A gate terminal of the sixth PMOS transistor **238** receives the exclusive OR output N2 **236** from the first inverter **235**. A source terminal of the sixth PMOS transistor **238** is coupled to the first node X **215**. A gate terminal of the sixth NMOS transistor **240** receives the output N1 **234** of the exclusive NOR logic circuit **205**. A source terminal of the sixth NMOS transistor **240** is coupled to the second node Y **217**.

A gate terminal of the seventh PMOS transistor **242** receives the third input C **206**. A source terminal of the seventh PMOS transistor **242** is coupled to the first node X **215**. A gate terminal of the seventh NMOS transistor **244** receives the third input C **206**. A source terminal of the seventh NMOS transistor **244** is coupled to the second node Y **217**. A drain terminal of the seventh NMOS transistor **244** is coupled to a drain terminal of the seventh PMOS transistor **242** to form a fourth node M **243**. A drain terminal of the sixth PMOS transistor **238** and a drain terminal of the sixth NMOS transistor **240** are coupled to the fourth node M **243**.

The inverted carry (\overline{Co}) **246** is generated at the fourth node M **243**. The inverted carry (\overline{Co}) **246** is defined as

$$(\overline{Co}) = \overline{(A+B)}(C + A \oplus B) \quad (5)$$

The second inverter **247** is coupled to the fourth node M **243**. The second inverter **247** generates a carry (Co) **248** on receiving the inverted carry (\overline{Co}) **246**. The full adder **200** further includes the fourth inverter **207** that generates an inverted third input (\overline{C}) **208** on receiving the third input C **206**.

The sum generation circuit **250** is explained now. The sum generation circuit **250** receives the output N1 **234** of the exclusive NOR logic circuit **205**, the exclusive OR output N2 **236** and the inverted third input (\overline{C}) **208**. The sum generation circuit **250** generates an inverted sum. The sum generation circuit **250** includes an eighth PMOS transistor **252**, an eighth NMOS transistor **254**, a ninth PMOS transistor **256** and a ninth NMOS transistor **258**. A gate terminal of the eighth PMOS transistor **252** receives the inverted third input (\overline{C}) **208**. A source terminal of the eighth PMOS transistor **252** receives the exclusive OR output N2 **236**.

A gate terminal of the eighth NMOS transistor **254** receives the inverted third input (\overline{C}) **208**. A source terminal of the eighth NMOS transistor **254** receives the output N1 **234** of the exclusive NOR logic circuit **205**. A gate terminal of the ninth PMOS transistor **256** receives the exclusive OR output N2 **236** and a source terminal of the ninth PMOS transistor **256** receives the inverted third input (\overline{C}) **208**.

6

A gate terminal of the ninth NMOS transistor **258** receives the output N1 **234** of the exclusive NOR logic circuit **205**. A source terminal of the ninth NMOS transistor **258** receives the inverted third input (\overline{C}) **208**. A drain terminal of the ninth NMOS transistor **258** is coupled to a drain terminal of the ninth PMOS transistor **256** to form a fifth node K **260**.

The sum generation circuit **250** generates the inverted sum which is generated at the fifth node K **260**. The inverted sum is defined as:

$$\text{Inverted Sum} = \overline{(A \oplus B)} \oplus \overline{C} \quad (6)$$

A drain terminal of the eighth PMOS transistor **252** and a drain terminal of the eighth NMOS transistor **254** are coupled to the fifth node K **260**. The third inverter **265** is coupled to the fifth node K **260** and generates the sum (S) **270** on receiving the inverted sum.

The operation of the full adder **200** illustrated in FIG. 2 is explained now with the help of logic states. In a state, when each of the first input A **202**, the second input B **204** and the third input C **206** is at logic '0', the first node X **215** is at logic '1' as well as the third node Z **219** is at logic '1' which represent the output N1 **234** of the exclusive NOR logic circuit **205**. Thus, the exclusive OR output N2 **236** generated by the first inverter **235** is at logic '0'. The carry generation circuit **245** on receiving N1 **234** and N2 **236** generates an inverted carry (\overline{Co}) **246** which is at logic '1' and thus the carry (Co) is at logic '0'. Also, the sum generation circuit **250** receives the inverted third input (\overline{C}) **208** (which is at logic '1'), the output N1 **234** of the exclusive NOR logic circuit **205** (which is at logic '1') and the exclusive OR output N2 **236** (which is at logic '0'). Thus, the sum generation circuit **250** through the ninth PMOS transistor **256** generates the inverted sum which is at logic '1'. The inverted sum is generated at the fifth node K **260**. The sum S **270** generated by the third inverter **265** is at logic '0'.

In a state, when the first input A **202** and the second input B **204** remain at logic '0' and the third input C **206** transitions to logic '1', the first node X **215** remains at logic '1'. As a result, the third node Z **219** remains at logic '1' which represent the output N1 **234** of the exclusive NOR logic circuit **205**. Thus, the exclusive OR output N2 **236** generated by the first inverter **235** remains at logic '0'. The carry generation circuit **245** on receiving N1 **234** and N2 **236** generates an inverted carry (\overline{Co}) **246** which is at logic '1' and thus the carry (Co) is at logic '0'. Also, the sum generation circuit **250** receives the inverted third input (\overline{C}) **208** (which is at logic '0'), the output N1 **234** of the exclusive NOR logic circuit **205** (which is at logic '1') and the exclusive OR output N2 **236** (which is at logic '0'). Thus, the sum generation circuit **250** through the ninth NMOS transistor **258** generates the inverted sum which is at logic '0'. The inverted sum is generated at the fifth node K **260**. The sum S **270** generated by the third inverter **265** is at logic '1'.

In a state, when the first input A **202** remains at logic '0' and the second input B **204** transitions to logic '1' and the third input C **206** transitions to logic '0', the first node X **215** remains at logic '1'. However, the third node Z **219** transitions to logic '0' through the third NMOS transistor **224** and the fifth NMOS transistor **232**. The third node Z **219** represent the output N1 **234** of the exclusive NOR logic circuit **205**. Thus, the exclusive OR output N2 **236** generated by the first inverter **235** is at logic '1'. The carry generation circuit **245** through the first PMOS transistor **212** and the seventh PMOS transistor **242** generates an inverted carry (\overline{Co}) **246** which is at logic '1' and thus the carry (Co) is at logic '0'. Also, the sum generation circuit **250** receives the inverted third input (\overline{C}) **208** (which is at logic '1'), the output

N1 234 of the exclusive NOR logic circuit 205 (which is at logic '0') and the exclusive OR output N2 236 (which is at logic '1'). Thus, the sum generation circuit 250 through the eighth NMOS transistor 254 generates the inverted sum which is at logic '0'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '1'.

In a state, when the first input A 202 remains at logic '0' and the second input B 204 transitions to logic '1' and the third input C 206 transitions to logic '1', the first node X 215 remains at logic '1'. The third node Z 219 remains at logic '0' through the third NMOS transistor 224 and the fifth NMOS transistor 232. The third node Z 219 represent the output N1 234 of the exclusive NOR logic circuit 205. Thus, the exclusive OR output N2 236 generated by the first inverter 235 is at logic '1'. The carry generation circuit 245 through the seventh NMOS transistor 244 and the fifth NMOS transistor 232 generates an inverted carry ($\overline{\text{Co}}$) 246 which is at logic '0' and thus the carry (Co) is at logic '1'. Also, the sum generation circuit 250 receives the inverted third input ($\overline{\text{C}}$) 208 (which is at logic '0'), the output N1 234 of the exclusive NOR logic circuit 205 (which is at logic '0') and the exclusive OR output N2 236 (which is at logic '1'). Thus, the sum generation circuit 250 through the eighth PMOS transistor 252 generates the inverted sum which is at logic '1'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '0'.

In a state, when the first input A 202 transitions to logic '1' and the second input B 204 transitions to logic '0' and the third input C 206 transitions to logic '0', the first node X 215 remains at logic '1'. However, the third node Z 219 transitions to logic '0' through the third NMOS transistor 224 and the fourth NMOS transistor 230. The third node Z 219 represent the output N1 234 of the exclusive NOR logic circuit 205. Thus, the exclusive OR output N2 236 generated by the first inverter 235 is at logic '1'. The carry generation circuit 245 through the second PMOS transistor 214 and the seventh PMOS transistor 242 generates an inverted carry ($\overline{\text{Co}}$) 246 which is at logic '1' and thus the carry (Co) is at logic '0'. Also, the sum generation circuit 250 receives the inverted third input ($\overline{\text{C}}$) 208 (which is at logic '1'), the output N1 234 of the exclusive NOR logic circuit 205 (which is at logic '0') and the exclusive OR output N2 236 (which is at logic '1'). Thus, the sum generation circuit 250 through the eighth NMOS transistor 254 generates the inverted sum which is at logic '0'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '1'.

In a state, when the first input A 202 remains at logic and the second input B 204 remains at logic '0' and the third input C 206 transitions to logic the first node X 215 remains at logic '1'. Also, the third node Z 219 remains at logic '0' through the third NMOS transistor 224 and the fourth NMOS transistor 230. The third node Z 219 represent the output N1 234 of the exclusive NOR logic circuit 205. Thus, the exclusive OR output N2 236 generated by the first inverter 235 is at logic '1'. The carry generation circuit 245 through the seventh NMOS transistor 244 and the fourth NMOS transistor 230 generates an inverted carry ($\overline{\text{Co}}$) 246 which is at logic '0' and thus the carry (Co) is at logic '1'. Also, the sum generation circuit 250 receives the inverted third input ($\overline{\text{C}}$) 208 (which is at logic '0'), the output N1 234 of the exclusive NOR logic circuit 205 (which is at logic '0') and the exclusive OR output N2 236 (which is at logic '1'). Thus, the sum generation circuit 250 through the eighth NMOS transistor 252 generates the inverted sum which is at

logic '1'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '0'.

In a state, when the first input A 202 remains at logic '1' and the second input B 204 transitions to logic '1' and the third input C 206 transitions to logic '0', the first node X 215 transitions to logic '0' through the first NMOS transistor 216 and the second NMOS transistor 218. Hence the third node Z 219 transitions to logic '1' which represent the output N1 234 of the exclusive NOR logic circuit 205. Thus, the exclusive OR output N2 236 generated by the first inverter 235 is at logic '0'. The carry generation circuit 245 on receiving N1 234 and N2 236 generates an inverted carry ($\overline{\text{Co}}$) 246 which is at logic '0' through the sixth NMOS transistor 240, the fourth NMOS transistor 230 and the fifth NMOS transistor 232. Thus the carry (Co) is at logic '1'. Also, the sum generation circuit 250 receives the inverted third input ($\overline{\text{C}}$) 208 (which is at logic '1'), the output N1 234 of the exclusive NOR logic circuit 205 (which is at logic '1') and the exclusive OR output N2 236 (which is at logic '0'). Thus, the sum generation circuit 250 through the ninth PMOS transistor 256 generates the inverted sum which is at logic '1'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '0'.

In a state, when the first input A 202 remains at logic '1' and the second input B 204 remains at logic '1' and the third input C 206 transitions to logic '1', the first node X 215 remains at logic '0' through the first NMOS transistor 216 and the second NMOS transistor 218. Hence the third node Z 219 remains at logic '1' which represent the output N1 234 of the exclusive NOR logic circuit 205. Thus, the exclusive OR output N2 236 generated by the first inverter 235 is at logic '0'. The carry generation circuit 245 on receiving N1 234 and N2 236 generates an inverted carry ($\overline{\text{Co}}$) 246 which is at logic '0' through the sixth NMOS transistor 240, the seventh NMOS transistor 244 and the fourth NMOS transistor 230 and the fifth NMOS transistor 232. Thus, the carry (Co) 248 is at logic '1'. Also, the sum generation circuit 250 receives the inverted third input ($\overline{\text{C}}$) 208 (which is at logic '0'), the output N1 234 of the exclusive NOR logic circuit 205 (which is at logic '1') and the exclusive OR output N2 236 (which is at logic '0'). Thus, the sum generation circuit 250 through the ninth NMOS transistor 258 generates the inverted sum which is at logic '0'. The inverted sum is generated at the fifth node K 260. The sum S 270 generated by the third inverter 265 is at logic '1'.

Table 1 summarizes the logic states of the full adder 200.

TABLE 1

A	B	C	First Node 'X'	Third Node 'Z'	N2	Co	S
0	0	0	1	1	0	0	0
0	0	1	1	1	0	0	1
0	1	0	1	0	1	0	1
0	1	1	1	0	1	1	0
1	0	0	1	0	1	0	1
1	0	1	1	0	1	1	0
1	1	0	0	1	0	1	0
1	1	1	0	1	0	1	1

The full adder 200 requires a total of 26 transistors which directly translates to reduction in chip area and saving of costs when compared to conventional full adder 100 illustrated in FIG. 1. Also, with less transistor count as compared to conventional full adder 100, the power consumed by the full adder 200 is also low. Since, the generation of carry (Co)

248 and the sum (S) 270 are independent, the full adder 200 provides a better processing speed as compared to conventional full adder 100. Thus, the sum (S) 270 is not dependent on the carry (Co) 248 which reduces the overall response time of the full adder 200 when the inputs transition from one state to another.

FIG. 3 illustrates a computing device 300, according to an embodiment. The computing device 300 is, or is incorporated into, a mobile communication device 325, such as a mobile phone, a personal digital assistant, a personal computer, or any other type of electronic system.

In some embodiments, the computing device 300 comprises a megacell or a system-on-chip (SoC) which includes control logic such as a processing unit 312 (Central Processing Unit), a memory module 314 (e.g., random access memory (RAM)) and a tester 310. The processing unit 312 can be, for example, a CISC-type (Complex Instruction Set Computer) CPU, RISC-type CPU (Reduced Instruction Set Computer), or a digital signal processor (DSP). The memory module 314 (which can be memory such as RAM, flash memory, or disk storage) stores one or more software application 330 (e.g. embedded applications) that, when executed by the processing unit 312, perform any suitable function associated with the computing device 300.

The tester 310 comprises logic that supports testing and debugging of the computing device 300 executing the software application 330. For example, the tester 310 can be used to emulate a defective or unavailable component(s) of the computing device 300 to allow verification of how the component(s), were it actually present on the computing device 300, would perform in various situations (e.g., how the component(s) would interact with the software application 330). In this way, the software application 330 can be debugged in an environment which resembles post-production operation.

The processing unit 312 typically comprises memory and logic which store information frequently accessed from the memory module 314. Various subsystems (such as the processing unit 312 and the memory module 314) of the computing device 300 include digital logic block 316 which are used during the execution of the software application 330. The digital logic block 316 includes a plurality of full adders illustrated as 320a, 320b, 320c and 320n.

At least one full adder of the plurality of full adders (320a-320n) is similar to the full adder 200 (illustrated in FIG. 2) in connection and operation. In one example, the full adder 320a is analogous to the full adder 200 in connection and operations. The full adder 320a has reduced power consumption and also the sum (S) is not dependent on the carry (Co) which reduces the overall response time of the full adder 320a when the inputs transition from one state to another.

In the foregoing discussion, the terms “connected” means at least either a direct electrical connection between the devices connected or an indirect connection through one or more passive intermediary devices. The term “circuit” means at least either a single component or a multiplicity of passive components, that are connected together to provide a desired function. The term “signal” means at least one current, voltage, charge, data, or other signal. Also, the terms “coupled to” or “couples with” (and the like) are intended to describe either an indirect or direct electrical connection. Thus, if a first device is coupled to a second device, that connection can be through a direct electrical connection, or through an indirect electrical connection via other devices and connections.

Further, the term “high” is generally intended to describe a signal that is at logic “1,” and the term “low” is generally intended to describe a signal that is at logic “0.” The term “on” applied to a transistor or group of transistors is generally intended to describe gate biasing to enable current flow through the transistor or transistors. Also, the terms “inactivation” or “inactivated” or turn “OFF” or turned “OFF” is used to describe a deactivation of a device, a component or a signal. The terms “activation” or “activated” or turned “ON” describes activation of a device, a component or a signal.

The foregoing description sets forth numerous specific details to convey a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the invention may be practiced without these specific details. Well-known features are sometimes not described in detail in order to avoid obscuring the invention. Other variations and embodiments are possible in light of above teachings, and it is thus intended that the scope of invention not be limited by this Detailed Description, but only by the following Claims.

What is claimed is:

1. A full adder comprising:

an exclusive NOR logic circuit configured to receive a first input and a second input;

a first inverter configured to receive an output of the exclusive NOR logic circuit and configured to generate an exclusive OR output;

a carry generation circuit configured to receive the output of the exclusive NOR logic circuit, the exclusive OR output and a third input, the carry generation circuit configured to generate an inverted carry; and

a sum generation circuit configured to receive the output of the exclusive NOR logic circuit, the exclusive OR output and the third input, the sum generation circuit configured to generate an inverted sum.

2. The full adder of claim 1 further comprising:

a second inverter coupled to the carry generation circuit and configured to generate a carry on receiving the inverted carry; and

a third inverter coupled to the sum generation circuit and configured to generate a sum on receiving the inverted sum.

3. The full adder of claim 1, wherein the exclusive NOR logic circuit comprises:

a first NAND logic circuit configured to receive the first input and the second input; and

a second NAND logic circuit configured to receive an output of the first NAND logic circuit, the first input and the second input, the second NAND logic circuit configured to generate the output of the exclusive NOR logic circuit.

4. The full adder of claim 3, wherein the first NAND logic circuit comprises:

a first PMOS transistor whose gate terminal is configured to receive the first input and whose drain terminal is coupled to a first node;

a second PMOS transistor whose gate terminal is configured to receive the second input and whose drain terminal is coupled to the first node, wherein a source terminal of each of the first PMOS transistor and the second PMOS transistor is coupled to a power terminal;

a first NMOS transistor whose gate terminal is configured to receive the first input and whose drain terminal is coupled to the first node; and

a second NMOS transistor whose gate terminal is configured to receive the second input and whose drain

11

terminal is coupled to a source terminal of the first NMOS transistor, wherein a source terminal of the second NMOS transistor is coupled to a ground terminal.

5. The full adder of claim 3, wherein the second NAND logic circuit comprises:

- a third PMOS transistor whose gate terminal is coupled to the first node and whose source terminal is coupled to the power terminal;
- a third NMOS transistor whose gate terminal is coupled to the first node and whose source terminal is coupled to a second node, wherein a drain terminal of the third NMOS transistor is coupled to a drain terminal of the third PMOS transistor to form a third node;
- a fourth PMOS transistor whose gate terminal is configured to receive the second input and whose source terminal is coupled to the power terminal,
- a fifth PMOS transistor whose gate terminal is configured to receive the first input and whose drain terminal is coupled to the third node, wherein a source terminal of the fifth PMOS transistor is coupled to a drain terminal of the fourth PMOS transistor;
- a fourth NMOS transistor whose gate terminal is configured to receive the first input and whose source terminal is coupled to the ground terminal; and
- a fifth NMOS transistor whose gate terminal is configured to receive the second input and whose source terminal is coupled to the ground terminal, wherein a drain terminal of the fifth NMOS transistor is coupled to a drain terminal of the fourth NMOS transistor to form the second node.

6. The full adder of claim 3, wherein the output of the exclusive NOR logic circuit is generated at the third node.

7. The full adder of claim 1, wherein the carry generation circuit further comprises:

- a sixth PMOS transistor whose gate terminal is configured to receive the exclusive OR output from the first inverter and whose source terminal is coupled to the first node;
- a sixth NMOS transistor whose gate terminal is configured to receive the output of the exclusive NOR logic circuit and whose source terminal is coupled to the second node;
- a seventh PMOS transistor whose gate terminal is configured to receive the third input and whose source terminal is coupled to the first node; and
- a seventh NMOS transistor whose gate terminal is configured to receive the third input and whose source terminal is coupled to the second node, wherein a drain terminal of the seventh NMOS transistor is coupled to a drain terminal of the seventh PMOS transistor to form a fourth node, such that the inverted carry is generated at the fourth node.

8. The full adder of claim 7, wherein a drain terminal of the sixth PMOS transistor and a drain terminal of the sixth NMOS transistor are coupled to the fourth node.

9. The full adder of claim 7, wherein the first PMOS transistor, the second PMOS transistor, the fourth NMOS transistor and the fifth NMOS transistor are shared between the carry generation circuit and the exclusive NOR logic circuit.

10. The full adder of claim 7, wherein the second inverter is coupled to the fourth node and configured to generate the carry on receiving the inverted carry.

11. The full adder of claim 1 further comprising a fourth inverter configured to generate an inverted third input on receiving the third input.

12

12. The full adder of claim 1, wherein the sum generation circuit comprises:

- an eighth PMOS transistor whose gate terminal is configured to receive the inverted third input and whose source terminal is configured to receive the exclusive OR output;
- an eighth NMOS transistor whose gate terminal is configured to receive the inverted third input and whose source terminal is configured to receive the output of the exclusive NOR logic circuit;
- a ninth PMOS transistor whose gate terminal is configured to receive the exclusive OR output and whose source terminal is configured to receive the inverted third input; and
- a ninth NMOS transistor whose gate terminal is configured to receive the output of the exclusive NOR logic circuit and whose source terminal is configured to receive the inverted third input, wherein a drain terminal of the ninth NMOS transistor is coupled to a drain terminal of the ninth PMOS transistor to form a fifth node, such that the inverted sum is generated at the fifth node.

13. The full adder of claim 12, wherein a drain terminal of the eighth PMOS transistor and a drain terminal of the eighth NMOS transistor are coupled to the fifth node.

14. The full adder of claim 12, wherein the third inverter is coupled to the fifth node and configured to generate the sum on receiving the inverted sum.

15. A method comprising:

- performing an exclusive NOR logic operation on a first input and a second input in an exclusive NOR logic circuit,
- inverting an output of the exclusive NOR logic circuit to generate an exclusive OR output,
- generating an inverted carry from the output of the exclusive NOR logic circuit, the exclusive OR output and a third input; and
- generating an inverted sum from the output of the exclusive NOR logic circuit, the exclusive OR output and the third input.

16. The method of claim 15 further comprising:

- inverting the inverted carry to generate a carry; and
- inverting the inverted sum to generate a sum.

17. A computing device comprising:

- a processing unit,
- a memory module coupled to the processing unit, the processing unit comprising
- a digital logic block, the digital logic block comprising a plurality of full adders,
- and a full adder of the plurality of full adders comprising:
 - an exclusive NOR logic circuit configured to receive a first input and a second input;
 - a first inverter configured to receive an output of the exclusive NOR logic circuit and configured to generate an exclusive OR output;
 - a carry generation circuit configured to receive the output of the exclusive NOR logic circuit, the exclusive OR output and a third input, the carry generation circuit configured to generate an inverted carry;
 - a second inverter coupled to the carry generation circuit and configured to generate a carry on receiving the inverted carry;
 - a sum generation circuit configured to receive the output of the exclusive NOR logic circuit, the exclusive OR output and the third input, the sum generation circuit configured to generate an inverted sum; and

13

a third inverter coupled to the sum generation circuit and configured to generate a sum on receiving the inverted sum.

18. The computing device of **17**, wherein the exclusive NOR logic circuit comprises:

- a first NAND logic circuit configured to receive the first input and the second input; and
- a second NAND logic circuit configured to receive an output of the first NAND logic circuit, the first input and the second input, the second NAND logic circuit configured to generate the output of the exclusive NOR logic circuit.

* * * * *

14